The Antiferromagnetic Structure of Polycrystalline NiO Films

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INTRODUCTION:

An important but as yet poorly-understood phenomenon is the pinning (fixing) of the magnetization direction of a ferromagnet coupled to an antiferromagnet, an effect referred to as exchange biasing or exchange anisotropy. When a ferromagnet / antiferromagnet sandwich structure during growth is subjected to an external magnetic field along a specific direction in the interfacial plane, the ferromagnet remains pinned in that direction [1]. The exchange coupling is reflected by a hysteresis loop that is offset from zero field by the exchange field. Rotation of the magnetization direction from this preferred direction may require magnetic fields as high as several hundred Oersted. While it is clear, in general, that the exchange coupling effect across the ferromagnetic / antiferromagnetic interface must originate from symmetry breaking at the interface, the microscopic origin of the phenomenon has remained a mystery.

A complete understanding of exchange biasing is not only an interesting scientific problem but an important technological one, as well. It is used everyday in the manufacturing of magnetic recording heads. Of particular importance in the development of ever-more sensitive read heads, which sense the small flux changes arising from the magnetic domains on the spinning disk, is the so-called spin valve head. It is based on the giant magneto resistance effect and is currently being developed for tomorrows products. A necessary step to the understanding of exchange biasing is to determine the magnetic structures of both the antiferromagnet and the ferromagnet at their interface. The formation of antiferromagnetic domains is believed to be of particular importance to explain the experimental observation that the exchange anisotropy at the interface is in most cases quite weak, on the order of 1% of the maximum possible value, given by theory for an ideal single domain antiferromagnet [2, 3].

EXPERIMENT:

X-ray magnetic linear and circular dichroism (XMLD, XMCD) in combination with photoemission microscopy is a very powerful tool to study the magnetic and structural properties of complex surface and interface structures. Using this technique we can distinguish between elements in a composite or a layered structure by the different energetic positions of the core level absorption edges, a demand only met by x-ray based techniques. The magnetic structure of ferromagnetically ordered systems is accessible via the magnetic circular dichroism effect. The magnetic structure of antiferromagnetically ordered systems can be investigated by the magnetic linear dichroism effect. These effects are based on a shift in the spectral weight of the multiplet split core level absorption edges depending on the relative orientation of the photon polarization and the spin orientation in the ferro- or antiferromagnet [4]. Together with the high spatial resolution that is achievable in electron microscopy, magnetic domains, areas of different orientation or magnitude of the magnetic moments, can thus be resolved. Imaging of ferromagnetic domains is a well established technique [5]. Here, we will demonstrate that photoemission electron microscopy is also able to detect and image the antiferromagnetic contrast due to antiferromagnetic domains at the surface of polycrystalline NiO, a material that is used in today's exchanged biased sensors.

PEEM2 is a full field imaging photoemission electron microscope that has been fully operational since summer 1998 at the bending magnet beam line 7.3.1.1 at the Advanced Light Source. PEEM2 uses the secondary electron yield upon illumination by x-rays for imaging. The beam line is optimized for high flux at the L absorption edges of the 3d transition metals around 700 eV and delivers linearly and circularly polarized soft x-rays into a focus of 30 μm. A spatial resolution of 25 nm has been achieved with PEEM2. It is possible to measure local absorption spectra with good statistics in reasonable times in areas as small as 100 nm [6].

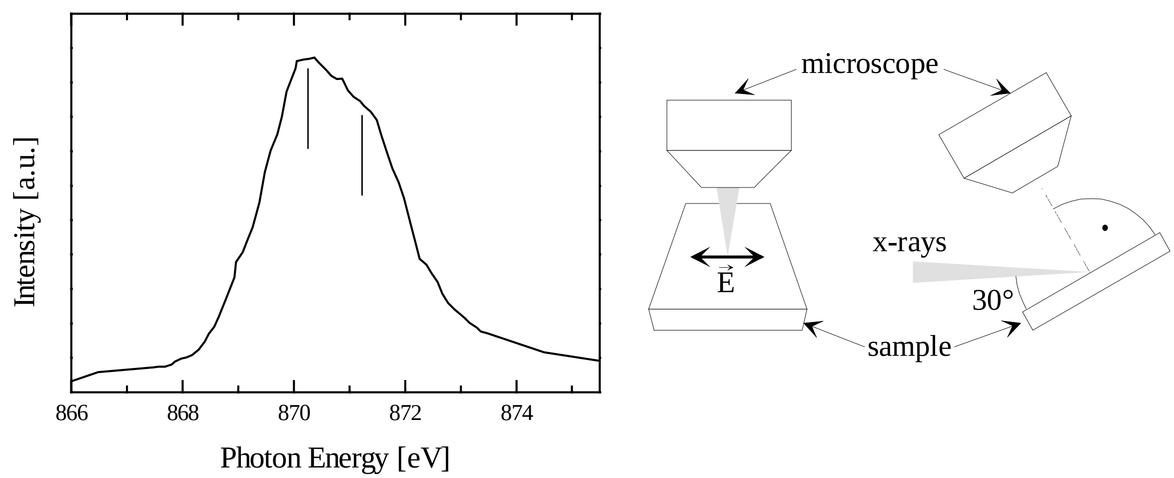

Fig. 1: X-ray absorption spectrum of polycrystalline NiO measured with PEEM in an area of about 20 μm diameter. Shown is the Ni L_2 edge measured with linearly polarized light. The measurement geometry is shown to the right.

RESULTS:

We have investigated 200 nm thick polycrystalline NiO layers that are sputter deposited on Si and are then annealed in O_2 to increase the size of the crystalline grains. As a rule of thumb a maximum grain size of 200 nm is to be expected for 200 nm thick films. The sample was transported in air before introducing it into PEEM2. Due to the high inertness of NiO no change in the morphology and magnetic structure should occur. The sample was then capped with about 2 nm Cu to get the electrically conductive surface necessary for photoelectron-based imaging. A thicker contact layer, about 20 nm thick, was grown using a masking technique, to achieve a good electrical connection. The capping was done in a separate preparation chamber connected with PEEM2.

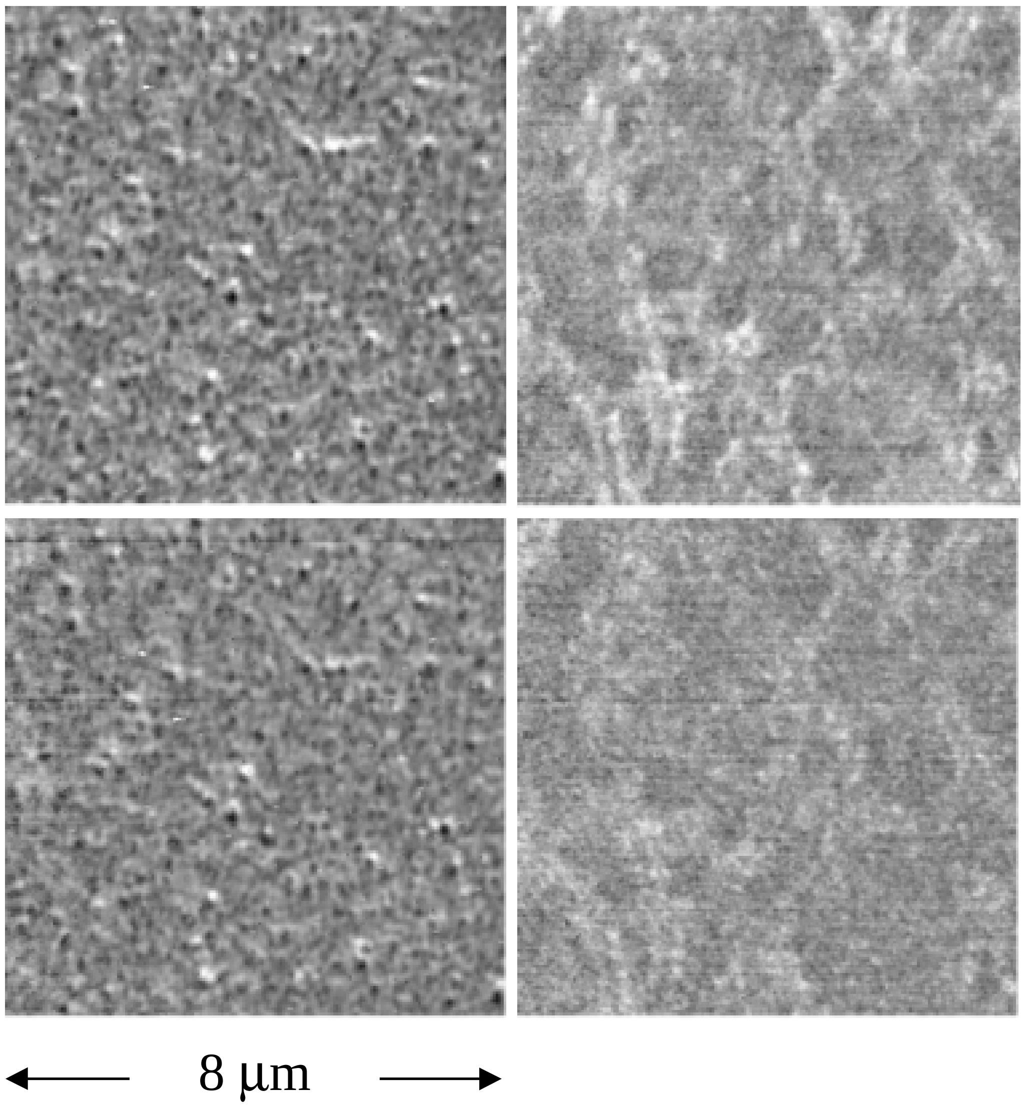

Fig. 2: The images show the topography (left) and the antiferromagnetic contrast (right) of polycrystalline NiO at room temperature (top) and at 100°C (bottom). The field of view is 8 µm.

Figure 1 shows an absorption spectrum of the NiO L_2 edge taken at room temperature with PEEM2. Linear polarized light was used. The polarization direction lies in the sample plane. The inset shows the measurement geometry. Here, the absorption was measured in a large area of about 20 µm diameter, so we averaged over many domains. The multiplet split L_2 edge consists of a peak at 872.2 eV and a shoulder separated from the main peak by about 1 eV. This profile is known to be typical for a magnetically ordered NiO layer with an average magnetization oriented perpendicular to the photon polarization [4]. For a non-magnetic NiO layer both peaks would have almost the same intensity. The intensity ratio at the multiplet split L_2 absorption edge, which is very sensitive to the relative orientation of photon polarization and spin direction, is then used to image with antiferromagnetic contrast, shown in figure 2. The four images were taken at the same spot on the sample at two different temperatures: room temperature (top) and at an elevated temperature of 100°C (bottom). The images showing the topography (left) result from averaging two images acquired on the two lines of the L_2 absorption edge. The images showing the antiferromagnetic structure result from dividing those two images. The image contrast is enhanced for better visibility.

The topography shows structures with a typical diameter of about 200 nm, visualizing the grain structure of the thin NiO layer. The topography does not change with temperature, demonstrating the stability of the NiO surface during modest heating in vacuum. The images on the right, acquired with antiferromagnetic contrast, show a very rich structure, demonstrating for the first time that x-ray absorption microscopy is suited to image the antiferromagnetic structure of ordered surfaces and interfaces through capping layers as thick as 2 nm. The decrease in magnetic contrast with increasing temperature results from the reduction of the NiO spin moment as its Néel temperature of 250°C is approached. This proves that the contrast arising from the peak ratio at the L2 edge is of magnetic origin. We believe that these results are a major breakthrough in understanding exchange biasing, since application of dichroism techniques in x-ray absorption combined with spatial resolution will enable the investigation of the complex magnetic structures at ferromagnet - antiferromagnet interfaces as well as domains and domain walls in model and in realistic systems.

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